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THE USE OF THE VIBRATION GALVANOMETER WITH A 60-CYCLE ALTERNATING CURRENT IN THE MEASUREMENT OF THE CONDUCTIVITY OF ELECTROLYTES

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In 1898 Kohlrausch (1) published a description of his method for determining the conductivity of electrolytes, and since that time much has been done by various investigators to increase the accuracy of the method. Notable among these are E. W. Washburn (2) and R. P. Hibbard in collaboration with C. W. Chapman (3). Still more recently has appeared an article by W. Taylor and S. F. Acree (5). Among the sources of error, which they have removed, may be mentioned the following: an alternating current from an induction coil which is neither strictly alternating nor of constant frequency; resistance coils which are inaccurate because of capacity and inductance; and lack of sensitivity in the telephone detector. At the present writing a series of articles is appearing in the Journal of the American Chemical Society by Dr. Washburn (4) which sums up the latest researches on the subject. To these articles any investigators who desire *absolute* accuracy of results are referred. The plant physiologist is concerned more with precise comparative data than with absolute physical accuracy, which must of necessity include experiments extending over long periods of time and involving great elaboration of method.

Dr. Washburn's method overcomes the difficulties mentioned above in the following manner: He uses for a source of current either the Vreeland Oscillator, which gives a pure sine wave at a frequency of one thousand cycles per second, or a constant-speed high-frequency generator which delivers an alternating current at the same frequency. Both of these pieces of apparatus and the principles involved are described in Catalog No. 48 of the Leeds and Northrup Co. (6). For resistance coils he uses the Curtis type, which have a minimum of inductance and capacity, and for the detector he uses a telephone receiver tuned to the frequency of the current. He also finds it

necessary in connection with the high frequency generator to maintain the correct resonance in the bridge circuit by means of a double condenser. Consequently a complete outfit for making conductivity measurements, using the generator and excluding bridge, conductivity cell and resistance coils, which are of course necessary in any form of apparatus, would cost over two hundred and fifty dollars. If the oscillator is substituted as a source of current the price is increased to about three hundred dollars. In either case a condenser must be used to balance out the capacity in the conductivity cell.

Hibbard and Chapman have met the problems as to source of current and detector in a different manner. They use a 60-cycle rotary converter and an alternating current galvanometer of the electro-dynamometer type. The latter costs about one hundred dollars. In addition, a rheostat is necessary to regulate the primary current. Consequently this apparatus exclusive of bridge, cell and resistances must cost as much or more than that employed by Washburn, without being applicable to as wide a variety of conditions. The physical chemist will occasionally need a current of higher frequency than 60 cycles, and such variation is impossible with the ordinary rotary converter. Obviously the main objection to both of these methods from the standpoint of the plant physiologist is the one of expense involved. This is especially significant when one considers that the apparatus employed serves one purpose only in the plant physiology laboratory, namely, that of measuring changes in permeability, or the electrolytic content of plant tissues and juices. Consequently the writer considers it likely that an apparatus embodying the latest methods of procedure, which fulfills all the requirements of precision, will be welcomed by workers along this line.

Since the investigators, whose results are cited above, have conducted the most exhaustive researches on the subject of conductivity measurements, it is certainly desirable to follow any procedure which they all recommend. We may assume then the necessity for a constant temperature bath, in which to immerse the conductivity cell, and a condenser to balance out the capacity in the cell. It is also certain that the Curtis coils are the most reliable of all available resistances, because they are so wound as to reduce inductance and capacity to a minimum. By standardizing the apparatus to this extent we are sure that the results obtained will have at least precise comparative values. We now come to the question of the source and type of current

to be used. Washburn is of the opinion that to avoid undue polarization in the conductivity cell, a frequency of 1,000 cycles per second is necessary. Moreover Taylor and Acree have shown that as the frequency approaches infinity, variations in the resistance and capacity of the cell approach zero. If we adopt this high frequency, the only available type of detector is the telephone receiver. On the other hand, Hibbard and Chapman, after exhaustive experimentation with lower frequencies, assert that at 60 cycles per second, using a cell with platinized electrodes, the amount of polarization is practically negligible in all but a few exceptional types of solutions. If this is the case the plant physiologist may feel secure in using this frequency, which has several great advantages over higher frequencies as will now be explained. An additional security rests in the fact that polarization, if present, is easily detected in the "creeping" of the balance point, and can be immediately remedied by cutting down the amount of current and the period of time in which the circuit is closed. The main advantage in using a low frequency lies in the fact that another detector than the telephone may be used. Such a detector is the alternating current galvanometer, of which there are two general types. The advantages of such a substitution are many and are fully discussed by Hibbard and Chapman. All who have worked with the telephone as detector will understand the difficulties attending the constant strain of listening, and will appreciate the substitution of a method which enables sight to take the place of hearing.

At this point the alterations in apparatus devised by the writer may properly be considered. If a frequency of 60 cycles per second is possible without a sacrifice in precision of comparative results, there should be some source of current more available and entailing less initial cost than the rotary converter. Such a source of current is present in practically every laboratory, and needs only to be reduced to the proper E.M.F. and potential. This is the ordinary 110-volt alternating-current lighting circuit. As supplied to the laboratory it is practically always a single-phase, 60-cycle system, having in most cases a frequency variation of not more than one percent and a remarkably pure wave form. Taylor and Acree in their article have inserted oscillograms of the Madison (Wis.) city current, which are by no means exceptional, and can be duplicated elsewhere. For example when this type of current is used to supply a bridge network in which the bridge-wire has a resistance of 1.2 ohms, the current

can be sufficiently reduced by the insertion in series of two 16 c.p. lamps. When the connections are made as in the diagram, the current passing through the bridge wire, if R and R' are open, is about .28 amperes at a potential of .336 volt.¹ In practice the resistances R and R' are in series with each other and the two connected in parallel with the bridge-wire. Then when the bridge is balanced, the current

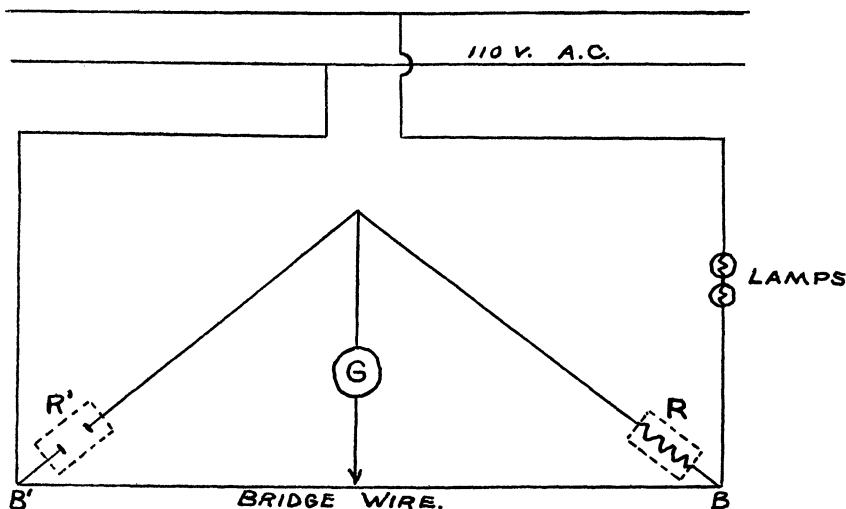


FIG. 1. For explanation see text.

divides itself between $R + R'$ and the bridge-wire, so that the two divisions of the current are in inverse proportion to the resistances of these parallel branches. Since the resistance of the bridge-wire is in this case 1.2 ohms and the resistance of the unknown (R') + its balance resistance (R) varies between 200 ohms for concentrated solutions and 10^6 ohms for conductivity water, it is easily seen that the amount of current passing through R' will be exceedingly small in all cases, running from .0016 ampere to 3.36×10^{-7} amp. If however heating occurs when a concentrated solution is being measured, it can easily be obviated by the introduction of a rheostat in series with the bridge-wire and lamps thus cutting the current down still further.

There now remains the consideration of the detector. For fre-

¹ The writer is indebted to Dr. Alan T. Waterman, of the Department of Physics of the University of Cincinnati, for assistance in calculating the electrical data.

quencies around 60 cycles the vibration galvanometer, as made by Leeds and Northrup for seventy-five dollars, is the most sensitive. It is easily tuned to the exact frequency of the current supply and once tuned needs attention only on rare occasions. Its sensitivity is such as to make profitable the use of the most accurate bridge with extensions on the bridge-wire. An added advantage is that the moving coil returns quickly to its neutral position when the circuit is broken, so that the band of light from the mirror follows closely in its width the position of the slider on the wire. This enables a speedy determination of the balance point and cuts down the chance of polarization.

The total cost of such an apparatus using the best bridge, resistances, conductivity cell and condensers will be much less than either the Washburn or the Hibbard and Chapman outfits. This is made possible by the substitution of the city current for an expensive piece of apparatus, which is itself often a source of annoyance because of noise. Moreover the vibration galvanometer is less expensive than the electro-dynamometer type, and there is no sacrifice in precision. The writer believes that these advantages will appear to be of distinct importance to plant physiologists and to others interested in conductivity measurements.

SUMMARY

Since Messrs. Hibbard and Chapman have shown that polarization is in nearly all cases a negligible factor using a current of 60-cycle frequency, the ordinary single-phase, 110-volt, a.-c. lighting circuit can be used as a source of current in making measurements of the conductivity of electrolytes.

With such a frequency the most sensitive and convenient detector is the vibration galvanometer.

The use of this method in preference to those previously known enables the investigator, who desires only precise comparative results, to make a considerable saving in first cost of apparatus without any attendant sacrifice in accuracy.

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